

(3) The plasma exposure can detach hydrogen from the surface of the second Mg-doped layer 17A more efficiently than the conventional annealing process, and Mg within the surface of the second Mg-doped layer 17A can be activated to a higher degree.

It should be noted that the p-side electrode 18 shown in FIG. 2 is also preferably alloyed by conducting plasma annealing at about 400° C. within a nitrogen ambient using the plasma processor 50 shown in FIG. 3. In such a case, it is possible to prevent the hydrogen atoms detached from being recombined with the p-type dopant in the semiconductor layer during an evaporation process step for forming electrodes, for example.

Also, part or all of the plasma processing may be performed not only to activate the acceptor, but also to alloy the electrodes.

Moreover, the p-side electrode 18 is preferably made of a hydrogen-storing metal. Specifically, the p-side electrode 18 may be made of titanium, magnesium, calcium, zirconium, lanthanum, niobium, vanadium, nickel, iron, manganese, cobalt, chromium or aluminum or may also be made of an alloy containing at least two of these. Also, the p-side electrode 18 should be formed so as to be in ohmic contact with the p-type contact layer 17B. In such a case, even if hydrogen detaches itself from the p-type semiconductor layer during the process step of activating the acceptor through plasma processing, that hydrogen can be adsorbed into the p-side electrode 18 made of a hydrogen-storing metal. Accordingly, it is possible to prevent the hydrogen atoms, which have detached themselves from the p-type semiconductor layer, from being recombined with the p-type dopant in the semiconductor layer.

Embodiment 2

Next, a second exemplary embodiment of the present invention will be described with reference to the accompanying drawings.

FIGS. 8(a), 8(b) and 9 are cross-sectional views illustrating respective process steps for fabricating a double-heterojunction nitride semiconductor laser device according to the second embodiment. In FIGS. 8(a), 8(b) and 9, the same members as those illustrated in FIGS. 1(a), 1(b) and 2 are identified by the same reference numerals, and the description thereof will be omitted herein.

First, as shown in FIG. 8(a), the respective epitaxial layers 12, 13, 14, 15, 16A and 17A are sequentially grown on the sapphire substrate 11 by an MOVPE process, for example, as in the first embodiment. As a result, the epitaxial substrate 20 is obtained. Thereafter, a hydrogen-adsorbing film 21 made of a hydrogen-storing metal or alloy is formed on the second Mg-doped layer 17A by sputtering or evaporation technique to a thickness of about 50 to about 100 nm.

Next, in the process step of activating the acceptor, the epitaxial substrate 20 including the hydrogen-adsorbing film 21 is introduced into the plasma processor 50 shown in FIG. 3, and then exposed to nitrogen plasma for about 40 minutes. As a result, Mg, or the p-type dopant, is activated and the p-type cladding layer 16B and p-type contact layer 17B are formed out of the first and second Mg-doped layers 16A and 17A, respectively, as shown in FIG. 8(b). In this case, since the hydrogen-adsorbing film 21 is formed on the second Mg-doped layer 17A, hydrogen, which has detached itself from the first and third Mg-doped layers 16A and 17A, is adsorbed into the hydrogen-adsorbing film 21. Accordingly, the hydrogen atoms detached are not recombined with the p-type dopant in the respective semiconductor layers on the epitaxial substrate 20.

Next, as shown in FIG. 9, when the p-side electrode 18 is patterned into a predetermined shape, the hydrogen-

adsorbing film 21 is also patterned into the same shape. Subsequently, the p-side electrode 18, hydrogen-adsorbing film 21 and p-type contact layer 17B are alloyed together by annealing the substrate at about 400° C. within a nitrogen ambient. This alloying process may be performed before the p-side electrode 18 is patterned.

It should be noted that the p-side electrode 18 is also preferably alloyed by conducting plasma annealing at about 400° C. within a nitrogen ambient using the plasma processor 50 shown in FIG. 3. In such a case, it is possible to prevent the hydrogen atoms, which have detached themselves from the p-type semiconductor layer, from being recombined with the p-type dopant in the semiconductor layer during an evaporation process step for forming electrodes, for example.

Also, part or all of the plasma processing may be performed not only to activate the acceptor, but also to alloy the electrodes.

The foregoing first and second embodiments may be modified as follows.

The substrate 11 may be made of silicon carbide (SiC), spinel or GaN, not sapphire.

The buffer layer 12 for relaxing the lattice mismatch between the substrate 11 and respective nitride semiconductors grown thereon may be GaN, instead of AlN.

In the foregoing embodiments, the p-type semiconductor layers are made of GaN and AlGa_{1-z}N. Alternatively, even when these layers are made of In_zGa_{1-z}N (where 0 < z ≤ 1) doped with Mg, the acceptor Mg can also be activated at a higher rate.

The p-type dopant to be an acceptor does not have to be Mg, but may be zinc (Zn), calcium (Ca), strontium (Sr), beryllium (Be), cadmium (Cd), mercury (Hg) or lithium (Li).

The p-side electrode 18 may be made of a single-layered metal simple substance selected from the group consisting of nickel (Ni), iron (Fe), copper (Cu), chromium (Cr), tantalum (Ta), vanadium (V), manganese (Mn), aluminum (Al), silver (Ag), palladium (Pd), iridium (Ir), gold (Au) and platinum (Pt). Alternatively, the p-side electrode 18 may be a stack of two or more layers made of respective metal single substances selected from the same group. Furthermore, the p-side electrode 18 may be made of an alloy containing at least two metals selected from the same group.

In the foregoing embodiments, a double-heterojunction semiconductor laser device has been described for the illustrative purposes only as a semiconductor device including a plurality of Group III nitride semiconductor layers with mutually different compositions stacked one upon the other. Instead, the present invention is applicable to any semiconductor device including at least one p-type nitride semiconductor layer.

Also, the plasma generator 50 is supposed to generate plasma by an RF process in the foregoing description. Alternatively, any other process like ECR or hot-wall process may be adopted so long as the epitaxial substrate 20 can be exposed to plasma uniformly.

What is claimed is:

1. A method for fabricating a semiconductor device, comprising the steps of:

- a) forming a semiconductor layer of a Group III nitride containing a dopant over a substrate; and
- b) exposing the semiconductor layer to a plasma with the temperature of the substrate kept at about 600° C. or lower for about 30 to 60 minutes, thereby making the conductivity type of the semiconductor layer p-type.

2. The method of claim 1, further comprising the step of c) forming a p-side electrode out of a metal on the semiconductor layer after the step b) has been performed.

11

3. The method of claim 2, wherein the step c) comprises annealing the p-side electrode at about 400° C. or lower after the p-side electrode has been performed.

4. The method of claim 2, wherein the step c) comprises exposing the semiconductor layer to a plasma after the p-side electrode has been formed.

5. The method of claim 1, wherein the plasma is generated by an RF, ECR or hot-wall process.

6. The method of claim 1, wherein the plasma comprises nitrogen plasma.

7. The method of claim 1, wherein the dopant is selected from the group consisting of magnesium, zinc, calcium, strontium, beryllium, cadmium, mercury and lithium.

8. A method for fabricating a semiconductor device, comprising the steps of:

a) forming a semiconductor layer of a Group III nitride containing a dopant over a substrate;

b) forming a p-side electrode out of a metal on the semiconductor layer; and

c) exposing the semiconductor layer to a plasma with the temperature of the substrate kept at about 600° C. or lower for about 30 to 60 minutes after the step b) has been performed, thereby making the conductivity type of the semiconductor layer p-type.

9. The method of claim 8, wherein the metal is selected from the group consisting of nickel, iron, copper, chromium,

12

tantalum, vanadium, manganese, aluminum, silver, palladium, iridium, gold and platinum.

10. The method of claim 8, wherein the metal is a hydrogen-storing metal selected from the group consisting of titanium, magnesium, calcium, zirconium, lanthanum, niobium, vanadium, nickel, iron, manganese, cobalt, chromium and aluminum.

11. The method of claim 8, wherein the step b) comprises forming a hydrogen-adsorbing layer out of a hydrogen-storing metal on the semiconductor layer before the p-side electrode is formed.

12. The method of claim 11, wherein the hydrogen-storing metal is selected from the group consisting of titanium, magnesium, calcium, zirconium, lanthanum, niobium, vanadium, nickel, iron, manganese, cobalt, chromium and aluminum.

13. The method of claim 8, wherein the plasma comprises nitrogen plasma.

14. The method of claim 1,

wherein in the step b), the temperature of the semiconductor layer is kept at about 400° C. or lower.

15. The method of claim 8,

wherein in the step (b), the temperature of the semiconductor layer is kept at about 400° C. or lower.

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